Spring influence of the Iberian Poleward Current into the Bay of Biscay from 1987 to 2006

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The main water mass present in the Bay of Biscay is the subpolar East North Atlantic Central Water (ENACWsp) which is defined by cold and low salinity waters. In winter and spring, the area was flowed by the Iberian Poleward Current (IPC) which is characterised by subtropical East North Atlantic Central Water (ENACWst) with high values of temperature and salinity (spicy waters). The intrusions of the IPC into the Bay of Biscay generate a mesoscale front due to the interaction of these two water masses. In order to characterise the IPC intrusions in the study area we used the spiciness (s), a state variable which is sensitive to isopycnal thermohaline variations and is defined as higher for warm and salty water. With the objective of determining the influence of the IPC in the southern Bay of Biscay we developed an iterative algorithm which works by using the distribution of spiciness along the shelf in search of a theoretical mesoscale frontal configuration (Fig. 1).

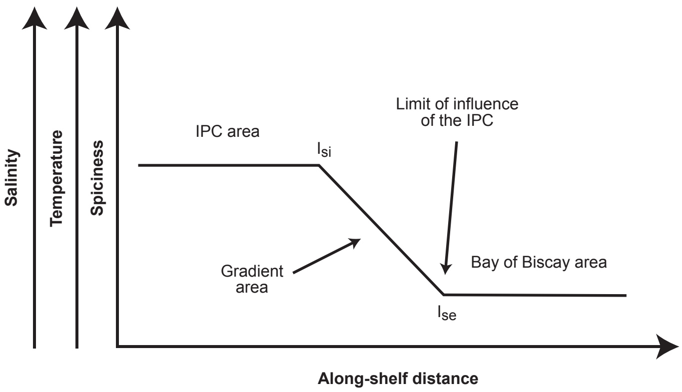

Figure 1. Schematic representation of the theoretical model of the interaction of relatively warmer and saltier water (ENACWst) of the IPC area and the relatively colder and fresher water (ENACWsp) of the Bay of Biscay area. The I_{si} and I_{se} are the beginning and end of the gradient area. These two parameters were iterated to obtain a better fit of the model to the field data (see Box 1 for details).

This methodology was applied for 19 spring cruises performed between 1987 and 2006 along the NW and N Iberian shelf. In all the cruises analysed we found a subsurface front that separates ENACWst advected by the IPC from the ENACWsp, the water mass characteristic of the Bay of Biscay. The position of this front (I_{se}) obtained by integrating the data from 10 to 140 m depth, varied from Finisterre (43.2°N, 8.9°W) to Ajo Cape (43.5° N, 4.0°W) and the mean situation was located between Cape Estaca de Bares and Cape Peñas (43.5°N, 7.0°W; Fig. 2). The influence of the IPC in the Cantabrian Sea was characterised by a significant mean increasing trend of 8.69 nm year^{-1} (n= 19, r= 0.71, p<0.001; Fig. 2). A correlation test was performed in order to discard the influence of seasonality in this interannual trend. A significant correlation between the penetration of the IPC in the Cantabrian sea and the start of the cruise was not found (n= 19, r= 0.30, p= 0.18).

Huthnance (1984) explained the dynamic of the IPC using the Joint Effect of Baroclinicity and Relief forcing (JEBAR). This

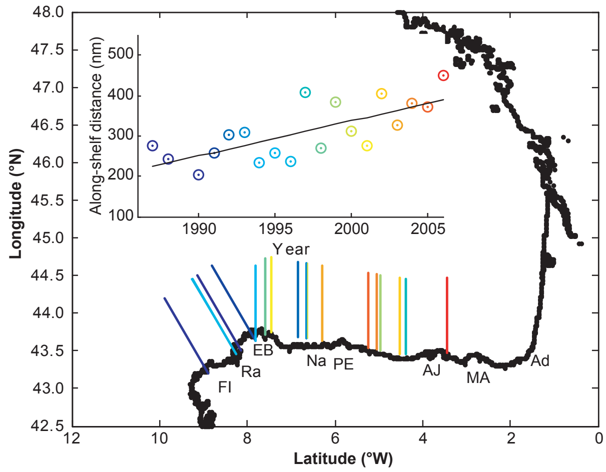

Figure 2. The position of the limit of influence of the IPC (I_{se}) obtained averaging the results from 10 to 140 m depth are represented by colour lines perpendicular to the coast. The colour of each line is related with the year of the cruise. In the inner axes were represent the linear trend of I_{se}. The main geographic features of the sampling area are, Cape Finisterre (FI), Rías Altas (Ra), Cape Estaca de Bares (EB), Nalón River (Na), Cape Peñas (PE), Cape Ajo (AJ), Cape Machichaco (MA) and Adour River (Ad).

theory assumes that the 80% of the variability of the IPC is a consequence of the North Atlantic density zonal gradient. This density gradient is generated primarily by the temperature zonal gradient. In order to verify this hypothesis we used a lag correlation analysis between the position of the IPC front and the sea surface temperature gradient (SSTg), calculated between 40°N and 50°N (Climate Prediction Centre, NOAA, http://www.cpc.ncep.noaa.gov). The two series were differentiated to make them stationary. We found a significant relationship between the limit of influence of the IPC and the averaged SSTg from July to October of the previous year (n= 16, r= 0.53, p= 0.02). This variable explains 30% of the IPC variability which is much less than the expected 80% stated in the literature (Peliz *et al.*, 2005).

The increasing trend of the IPC, from 1987 to 2000, and its relationship with ocean features and atmospheric climate processes, has important implications since it may influence the development of plankton and pelagic communities in a critical part of the annual production cycle. The impact of the intrusions of ENAWCst into the Cantabrian Sea have been investigated in relation to the distribution of picoplankton (Morán *et al.*, in press), phytoplankton (Bode *et al.*, 2002), zooplankton (Cabal *et al.*, 2006), sardine eggs (Baldó and Bernal, pers. comm.) and fish populations (Sánchez and Gil, 2000). Thus, a better understanding of the mechanisms which modulate the dynamics of the IPC during this part of the year will allow us to perform more accurate predictions of plankton dynamics, including early stages of fish species in order to improve the management of fisheries using the ecosystem approach (FAO, 2003).

Box 1. Iberian Poleward Current front model

In order to characterise the IPC intrusions in the study area we used spiciness (s), a state variable which is sensitive to isopycnal thermohaline variations and is defined to be higher for warm and salty water. This current generates a frontal structure which is characterised by three areas, the IPC area, with constant high values of spiciness, the Bay of Biscay area with constant low values of spiciness and the intermediate area characterised by a spiciness gradient between the IPC area values and the Bay of Biscay area values. This theoretical model was formalised following the equations [1], [2] and [3].

$$s_{IPC} = \frac{\sum_{1}^{n(l<l_{si})} s'(l < l_{si})}{n(l < l_{si})} \qquad l < l_{si} \qquad [1]$$

$$s_{grd} = \frac{s_{se} - s_{si}}{l_{se} - l_{si}} l + \frac{s_{si} l_{se} - s_{se} l_{si}}{l_{se} - l_{si}} \qquad l_{si} < l < l_{se} \qquad [2]$$

$$s_{bay} = \frac{\sum_{1}^{n(l>l_{se})} s'(l > l_{se})}{s(l > l_{se})} \qquad l > l_{se} \qquad [3]$$

The modelled values of the spiciness of the IPC area (s_{IPC}) and in the Bay of Biscay area (s_{bay}) were the average of the measured spiciness (s') of each corresponding area. The values in the gradient area were calculated using a linear function passing between (l_{si}, s_{IPC}) and (l_{se}, s_{bay}). The best fit of the function was obtained by minimising r in equation [4] using an iterative method.

$$r = \sum_{1}^{n} |s_i' - s_i| \qquad [4]$$

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